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Publication date:
2017

Document Version
Publisher's PDF, also known as Version of record

Citation (APA):
Batchvarova, E., Kirova, H., Gryning, S-E., Skov, H., & Sørensen, L. L. (2017). *How do PBL schemes in WRF describe summer and winter conditions at a high arctic site?*. Paper presented at 18th conference on Harmonisation within Atmospheric Dispersion Modelling for Regulatory Purposes, 2017, Bologna, Italy.

HOW DO PBL SCHEMES IN WRF DESCRIBE SUMMER AND WINTER CONDITIONS AT A HIGH ARCTIC SITE?

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Abstract: We compare 4 planetary boundary layer (PBL) schemes of Weather Research and Forecasting model for high Artic conditions, documented during summer and winter campaigns at Station Nord, Greenland. During March 2012, 22 radio sondes were launched at 00 and 12 UTC. During July-August 2011, 25 radio sondes were launched at 00, 06, 12, and 18 UTC. The chosen PBL schemes are 3 TKE schemes: MYJ, MYNN and QNSE and non-local YSU. Comparison is performed between data from radio soundings and corresponding in time model results up to different height from 100 m to 8000 m. Sensitivity of model to vertical and spatial resolution is examined with MYJ through 4 configurations combining 26 or 42 vertical levels and 4 km or 1.33 km horizontal grid step. Sensitivity to the resolution tests showed that increasing horizontal resolution from 4 km to 1.33 km did not improve model performance. Increasing the number of vertical layers lead to closer to observed profiles and slightly improved statistics by layers. Sensitivity to the lead time (24 h or 48 h) is examined with MYJ at 1.33 km grid step and 42 vertical layers. Quality of forecast for day 1 and day 2 is similar for the summer. Temperature and wind speed biases for the winter are with 1 K and 1 ms^{-1} larger for 48 h compared to 24 h lead time. The lack of diurnal variability during both campaigns is correctly simulated by all PBL schemes. The performed tests show that TKE schemes outperform YSU and as a whole MYNN gives the highest scores.

***Key words:**.Arctic site, Planetary boundary layer, WRF model, radio soundings*

INTRODUCTION

Station Nord, Greenland (81.65N, 16.65W, altitude 36 m) is a military and scientific station on Princess Ingeborg Peninsula in northeastern Greenland in National Park of Greenland (Fig. 1). During the last 5 years a Villum Research Station was built by Aarhus University, Denmark to foster research in the Arctic.

EXPERIMENTAL CAMPAIGNS AND METHODS

Two experimental campaigns (Gryning and Batchvarova, 2012) took place at Station Nord, as part of Cryosphere-Atmosphere Interactions in a Changing Arctic Climate project (NCoE-CRAICC**)**. During the winter campaign (03.03 – 18.03.2012) 22 radio soundings were performed at 00 and 12 UTC. The sun elevation at noon was between 2 and 8 degrees and the day length between 6:47 and 12 h. The summer experiment lasted 10 days (28.07 – 05.08.2011) at snow-free conditions at the site, Fig. 1 (middle). The sun elevation was between 10 and 32 degrees. The programme of the campaign included 4 soundings per day (00, 06, 12 18 UTC). The total number of launched sounds was 25. Additionally, cloud base height measurements were performed using a CL51 Vaisala ceilometer. Preliminary results of the studies are discussed in Batchvarova et al, 2013 and 2014.

The initial and boundary conditions for Advanced Research WRF (ARW) version 3.4 (Scamarock et al., 2008) are provided by the US National Center for Environmental Prediction (Final) Operational Global Analysis (FNL). Data for land-use is obtained from USGS 24. The numerical experiments are performed on the Hybrid HPC Cluster at Institute of Information and Communication Technologies – BAS (Atanassov et al., 2014). The sensitivity to the horizontal and vertical resolution is studied by 2 configurations on 3 and 4 domains (Fig. 1) with horizontal grid step of 36 km (D01), 12 km (D02), 4 km (D03) and 1.33 km (D04) with 26 and 42 levels going up to 50 hPa (simulations are denoted as "4 km 26 lev", "4 km 42 lev", "1.33 km 26 lev", "1.33 km 42 lev", respectively) with a local closure Mellor-Yamada-Janjic (MYJ; Mellor and Yamada, 1982; Janjic, 2002) PBL with Eta similarity surface layer (Janjic, 1996; 2002). Morrison scheme (Morisson et al., 2009) is chosen for microphysics, Rapid Radiative Transfer Model for longwave radiation (Mlawer et al., 1997), Goddard scheme (Chou and Suarez, 1994) for shortwave radiation, Noah land surface model (Tewari et al., 2004) for land surface processes, the cumulus parameterisation scheme Grell3D (improved version of Grell and Devenyi, 2002) is used only for domains D01 and D02.

Figure 1. Model configuration (left), and experimental site (middle, Photo: Sven-Erik Gryning) during the summer campaign in 2011 and The Villum Research Station (VRS) main building (right, Photo: Henrik Skov)

Additional test is performed to the sensitivity to forecast lead time (24 hours and 48 hours) using configuration on 3 domains with 42 vertical levels and MYJ PBL scheme. The same vertical model structure and configuration on 4 domains is used with 4 different PBL schemes: local schemes: MYJ, Mellor-Yamada-Nakanishi-Niino (MYNN 1.5 closure, level 2.5, Nakanishi and Niino, 2006), Quasi-Normal Scale Elimination (QNSE, Sukoriansky et al., 2005, 2006) and nonlocal-Yonsei University (YSU, Hong et al. (2006)), denoted as "MYNN", "QNSE" and "YSU" with corresponding surface layer schemes. The other options for the rest of physics were the same as in sensitivity tests. These eight configurations were run for summer (28.07 – 06.08.2011) and winter (03.03 – 18.03.2012) conditions in high Arctic. The simulations are performed with 12 hours spin up and each run consists 84 hours starting at 12 UTC.

The model is evaluated against the radio-sounding data using the following statistical metrics: mean (model mean), bias (model-observation), normalized root mean square error (NRMSE), and Pearson correlation coefficient (*r*). The studied parameters are temperature (*T*), potential temperature (Θ), relative humidity (*RH*) and wind speed (*WS*).

RESULTS

Results of the model behavior in the first 100 m, 200 m, 400 m, 600 m, and 2000 m from the ground (Fig 2, summer campaign) reveal that the configurations using identical vertical structure of atmosphere performs in similar way. The highest values of r_θ and r_{WS} are obtained for configuration "1.33 km 42lev" for both campaigns and smaller biases for the WS ($biase_\theta$ from "1.33 km 42lev" in the first 100 m and 200 m are higher during the winter compared with other configurations) and NRMSE. The impact of the resolution is revealed in the first 100-200 m above the ground.

The dataset used to perform the test to forecast lead time comprises model output and data up to 8000 m. The model output is evaluated against observations for 24 h and 48 h lead time separately for the summer and winter campaigns (Table 1). For the summer campaign quality of the forecast for day 1 and day 2 is similar. For the winter campaign distinguishes between day 1 and day 2 are more pronounced in biases-bias for θ and WS are with 1.2 K and 1 ms^{-1} respectively larger for 48 h than for 24 h.

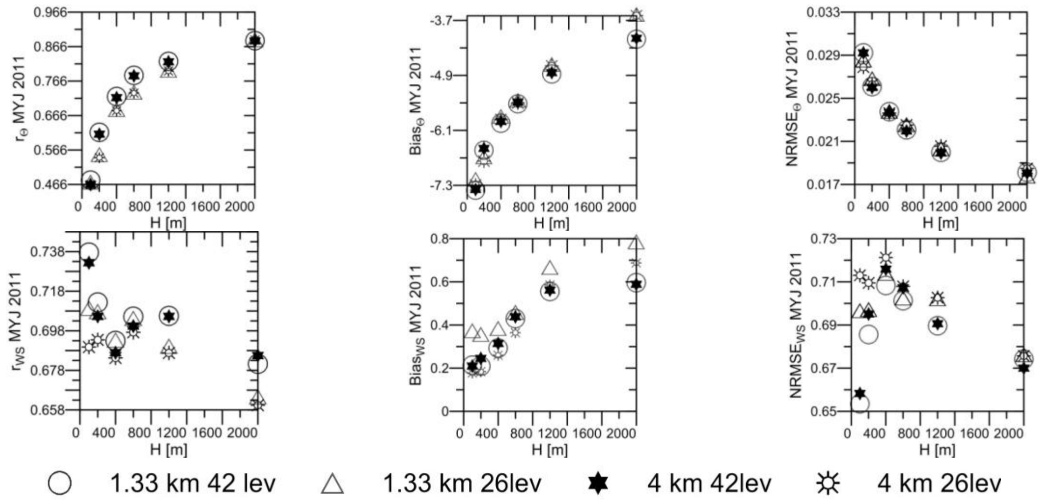

Figure 2. Sensitivity to the resolution: summer campaign results for the first 100 m, 200 m, 400 m, 600 m, 1000 m and 2000 m from the ground obtained with MYJ PBL scheme

Table 1. Model evaluation for 24 h and 48 h lead time up to 8000 m

		2011				2012			
		Mean	**Bias**	**NRMSE**	**r**	**Mean**	**Bias**	**NRMSE**	**r**
24 h	**T**	272.0	-3.9	0.0	0.97	249.0	2.4	0.0	0.84
	Θ	284.7	-2.9	0.0	0.97	261.2	3.5	0.0	0.95
	RH	70.9	12.6	0.4	0.68	69.0	0.2	0.4	0.37
	WS	7.3	0.8	0.5	0.83	9.7	2.1	0.6	0.77
48 h	**T**	271.9	-3.8	0.0	0.96	250.2	3.6	0.0	0.81
	Θ	284.4	-2.8	0.0	0.96	262.4	4.7	0.0	0.95
	RH	71.3	10.9	0.4	0.71	70.8	1.9	0.4	0.32
	WS	6.0	0.2	0.6	0.78	10.7	3.1	0.7	0.72

Table 2 (a,b) presents the model mean, bias, NRMSE and r of θ, RH and WS for both campaigns. The dataset comprises profiles up to 8000 m at different times of observation. All studied parameters are overestimated by the model except T, θ in the summer (bias<0) and RH in the winter (but $bias_{RH} > 0$ of YSU). Higher correlations are obtained for the summer campaign (except WS at noon) and smaller deviations from observations (except RH and T, lower winter biases for θ are obtained by MYNN and QNSE run). There is positive correlation between observed and modelled (by for 4 runs) parameters varying from strong ($0.6 \leq r \leq 0.79$) for RH (summer campaign) and WS (for winter and at 12 UTC for summer campaign) to extremely strong ($0.8 \leq r \leq 1$) for T, θ and WS (at 0, 06, 18 UTC for summer campaign). RH is unsatisfactory reproduced by 4 runs in winter campaign with weak ($0.2 \leq r \leq 0.39$) to moderate correlation ($0.4 \leq r \leq 0.59$). The highest values of r and the lowest values of other scores are obtained by simulations with TKE schemes (except for WS at noon in winter when YSU run is outperformed only by MYNN run). The modelled θ, T and RH by 4 runs are comparable in summer as the values of MYNN r are relatively higher than other runs. WS is simulated with the smallest biases by MYJ but with higher r by MYNN in summer. During winter campaign differences between the four runs are more prominent for θ, T and RH. All runs correctly represented the lack of diurnal variability in Artic conditions during both campaigns.

Table 2a. Statistical metrics for the summer campaign up to 8000 m

2011			Θ				RH				WS			
	pairs	**h**	**Mean**	**Bias**	**NRMSE**	**r**	**Mean**	**Bias**	**NRMSE**	**r**	**Mean**	**Bias**	**NRMSE**	**r**
MYJ	271	0	284.0	-3.1	0.0	0.96	74.2	10.2	0.3	0.70	6.6	0.9	0.6	0.84
	199	6	285.2	-3.1	0.0	0.97	66.0	12.0	0.4	0.70	7.0	0.5	0.5	0.80
	236	12	285.1	-2.6	0.0	0.97	68.2	13.9	0.4	0.71	6.0	0.4	0.7	0.62
	136	18	285.7	-4.1	0.0	0.97	73.8	24.9	0.6	0.74	7.5	1.1	0.5	0.87
MYNN	271	0	283.9	-3.2	0.0	0.96	74.3	10.3	0.3	0.69	6.4	0.7	0.6	0.86
	199	6	285.2	-3.1	0.0	0.97	66.4	12.4	0.4	0.71	7.6	1.0	0.5	0.83
	236	12	285.0	-2.7	0.0	0.97	69.0	14.7	0.4	0.77	6.4	0.8	0.7	0.66
	136	18	285.4	-4.3	0.0	0.98	74.9	26.1	0.6	0.76	7.4	0.9	0.5	0.88
QNSE	271	0	283.7	-3.4	0.0	0.95	74.2	10.2	0.3	0.69	6.3	0.6	0.6	0.86
	199	6	285.0	-3.3	0.0	0.97	67.0	13.0	0.4	0.70	7.4	0.8	0.5	0.83
	236	12	284.8	-2.9	0.0	0.97	69.7	15.4	0.4	0.75	6.3	0.7	0.7	0.66
	136	18	285.6	-4.3	0.0	0.97	74.1	25.2	0.6	0.73	7.4	1.0	0.5	0.87
YSU	267	0	283.5	-3.4	0.0	0.94	76.7	11.6	0.3	0.70	6.9	0.6	0.5	0.86
	199	6	284.8	-3.5	0.0	0.96	68.7	14.7	0.5	0.70	7.5	0.9	0.5	0.82
	236	12	284.6	-3.1	0.0	0.96	70.9	16.3	0.5	0.70	6.4	0.8	0.7	0.63
	136	18	285.4	-4.5	0.0	0.96	76.1	27.2	0.7	0.66	7.2	0.7	0.4	0.90

Table 2b. Statistical metrics for the winter campaign up to 8000 m

2012			Θ				RH				WS			
	pairs	**h**	**Mean**	**Bias**	**NRMSE**	**r**	**Mean**	**Bias**	**NRMSE**	**r**	**Mean**	**Bias**	**NRMSE**	**r**
MYJ	372	0	262.1	3.9	0.0	0.97	69.4	-0.1	0.4	0.37	12.6	3.5	0.8	0.72
	403	12	262.1	3.8	0.0	0.95	69.6	1.8	0.4	0.38	9.8	2.3	0.7	0.76
MYNN	370	0	260.6	2.7	0.0	0.97	64.9	-4.5	0.4	0.38	12.0	3.2	0.7	0.73
	404	12	260.9	2.6	0.0	0.96	67.0	-0.8	0.4	0.45	9.2	1.7	0.6	0.80
QNSE	370	0	260.7	2.8	0.0	0.96	66.5	-2.8	0.4	0.39	12.7	3.9	0.9	0.65
	404	12	261.0	2.7	0.0	0.95	66.6	-1.1	0.4	0.43	10.2	2.6	0.7	0.74
YSU	370	0	262.1	4.2	0.0	0.96	70.8	1.3	0.4	0.38	12.2	3.3	0.8	0.69
	403	12	262.5	4.2	0.0	0.94	71.2	3.3	0.4	0.35	9.6	2.1	0.6	0.78

CONCLUSION

The features of the Arctic boundary layer during winter (land and sea covered by snow/ice) and summer (sea covered by sea ice) were examined with WRF model version 3.4.1 and compared with radio-sounding data collected at Station Nord, Greenland. Sensitivity to the resolution tests revealed that increasing the horizontal resolution from 4 km to 1.33 km does not improve model performance. Increasing the vertical resolutions from 26 to 42 levels lead to slightly better statics by layers.

Evaluation of model output against observations for 24 h and 48 h lead time revealed that for the summer campaign quality of the forecast for day 1 and day 2 was similar. For the winter campaign, differences between day 1 and day 2 of the forecast were more pronounced: biases for θ and WS are with 1 K and 1 ms^{-1} respectively larger for 48-h than to 24-h lead time.

Comparison between runs with MYJ, MYNN, QNSE and YSU PBL schemes up to 8000 m showed that 4 runs correctly simulated the lack of diurnal variability during both campaigns. Summer campaign was simulated with higher values of r and lower biases. There was positive extremely strong correlation for θ, strong to extremely strong for WS for both campaigns. Weak to moderate correlation was found for RH in winter and strong correlation for summer. The four simulations gave close results, but MYNN simulation showed slightly better scores for the studied parameters.

Results for the first 100 m, 200 m, 400 m, 600 m, 1000 m, 2000 m from the ground showed that higher values of r were obtained in summer (except for θ) with lower biases and NRMSE. Increasing the depth of the layer led to higher r_θ and r_{RH} smaller errors for all runs and both seasons, while in summer for r_{WS} decrease with increase of the depth of the layer. θ was underestimated in 4 runs during summer and overestimated during winter while WS and RH were overestimated in 4 runs for both campaigns (except RH in 2000 m layer in winter). MYNN simulation outperformed the other 3 runs (except for WS in summer, where the best results are obtained by QNSE). In general, MYNN performed better compared MYJ, QNSE and YSU in summer, while in winter the performance was similar.

ACKNOWLEDGMENTS

The Department of Environmental Science, Aarhus University is acknowledged for providing logistics at Villum Research Station in North Greenland. This study is part of NIMH-BAS project “Study of Atmospheric Boundary Layer (ABL) in coastal areas”.

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